TABLE OF CONTENTS

	Page	
ABSTRACT	iv	1/A6
SECTION 1 - SUPERCONDUCTING MAGNET AND BATTERY ENERGY STORAGE SYSTEM MODELING	1	1/A7
1.1 Simplified Models	1	1/A7
1.2 Computer Simulations	4	1/A10
1.3 Computer Studies	8	1/B1
1.4 Conclusions	12	1/B5
1.5 References	20	1/B13
SECTION 2 - REDUCED ORDER MODELS OF THE DOUBLY-FED INDUCTION MACHINE	21	1/B14
SECTION 3 - POWER SYSTEM IDENTIFICATION	22	1/C1
3.1 Load Variation Model	22	1/C1
3.2 Direct Computation of Measurement Spectra	23	1/C2
3.3 Work Planned	24	1/C3
3.4 References	27	1/C6

APR 1 0 1978

11-429-T-4

ERDA-COO-4206-1

ENERGY CONSERVATION

COO-4206-1

COMPLETED
ORIGINAL

SECURITY ASSESSMENT OF POWER SYSTEMS INCLUDING ENERGY STORAGE

Progress Report, January 1, 1977–July 1, 1977

By
D. P. Carroll
D. M. Triezenberg

Date Published–September 1977

Work Performed Under Contract No. EC-77-S-02-4206

Energy Systems Simulation Laboratory
Purdue University
West Lafayette, Indiana

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

Division of Electric Energy Systems

(33)

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161

Price: Paper Copy $4.00 (domestic)
$6.50 (foreign)
Microfiche $3.00 (domestic)
$4.50 (foreign)

ERDA/COO-4206-1

COO-4206-1
Distribution Category UC-97c

SECURITY ASSESSMENT OF POWER SYSTEMS INCLUDING ENERGY STORAGE

Progress Report
for Period January 1, 1977 - July 1, 1977

D. P. Carroll and D. M. Triezenberg

July 1977

Prepared For

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
THE UNDER CONTRACT NO. EC-77-S-02-4206.A000

Energy Systems Simulation Laboratory
School of Electrical Engineering
Purdue University
West Lafayette, Indiana 47907

CONTRACT ACTIVITY

The principal investigators have devoted 25% of their workload to this contract since January, as scheduled. This is expected to continue through the remainder of the year.

ABSTRACT

Energy Storage

Using reference frame formulations, simplified analytical models have been developed for superconducting magnets and storage batteries interfaced with conventional line commutated power converters. The simplified models account for the controllable dynamics of these units, while neglecting the higher frequency harmonics produced by the converter circuit. For purposes of verification, these simplified models were incorporated in a computer simulation of a one-machine/infinite-bus power system equivalent. The validity of the simplified models for control studies is demonstrated by comparison of waveforms taken from another more detailed simulation of the same power system. The studies performed on the one-machine system also provide some preliminary insight into the control of energy storage units for improving power system stability.

Work has also begun in the development of reduced order models of induction machines, with primary emphasis on the doubly-fed machine. Eigenvalue and computer simulation studies are being conducted to determine the usefulness of the reduced order models.

Identification

A tentative model for load variations has been established and appears to not conflict with available knowledge on such variations. The capacity has been developed to determine analytically the spectral density function of any signal that can be measured on a power system, given this load variation model.

SECTION 1

SUPERCONDUCTING MAGNET AND BATTERY ENERGY STORAGE SYSTEM MODELING

This part of the progress report concerns the modeling and simulation of superconducting magnet and storage battery units connected to a power system through line-commutated converter (LCC) interfaces. A superconducting magnet (with converter) is referred to herein as an inductor-converter (IC) unit , and a storage battery (with converter) is referred to as a battery-converter (BC) unit. During this phase of the project simplified analytical models have been developed for line-commutated IC and BC units. For test purposes, these simplified models have been incorporated in a computer simulation of a one-machine/infinite-bus power system equivalent. A detailed three-phase representation of this system was also simulated for verification of the simplified models.

1.1 Simplified Models

The simplified model developed here for a 12-pulse LCC is based on ac reference frame theory and is similar to previous modeling of parallel ac/dc transmission systems [1]. The simplified converter model can be used directly with the equivalent circuit of a superconducting magnet or a storage battery, in order to form analytical models for line-commutated IC and BC units. The converter model is related directly to the ac bus supplying the converter, and therefore, can be conveniently used in a system of arbitrary configuration. In developing the simplified model, it is assumed that ac bus voltages are balanced and sinusoidal, and the direct current is constant. The bus voltages are represented in a synchronously rotating reference frame by the quantities v_q and v_d.

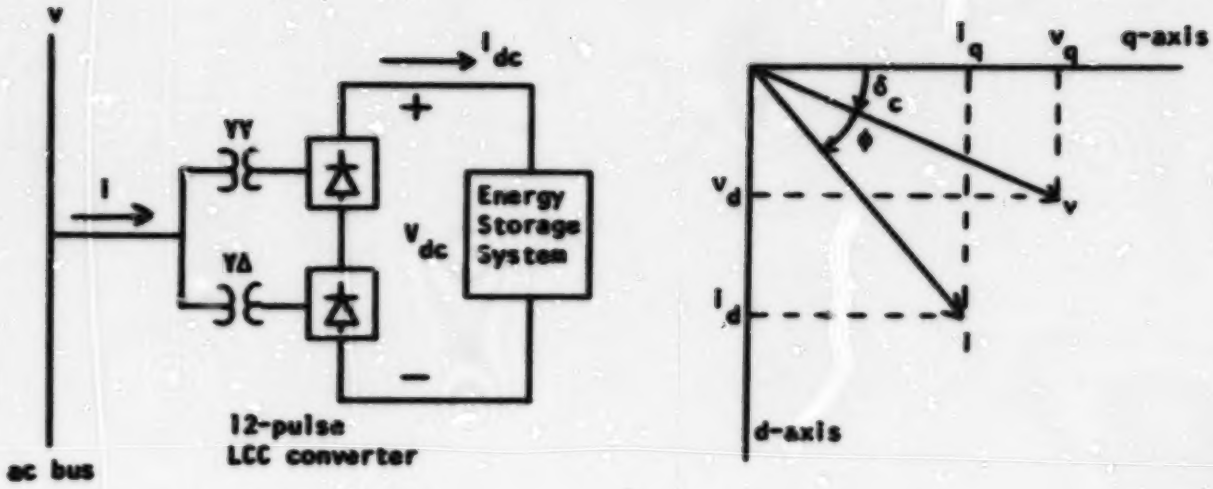

Fig. 1 Simplified Model Representations

From Fig. 1 it is clear that the amplitude of the bus voltage, defined as the crest phase-to-neutral voltage, is given by

$$E_m = \sqrt{V_q^2 + V_d^2} \tag{1}$$

and

$$\delta_c = \tan^{-1}\left(\frac{V_d}{V_q}\right), \quad -180° < \delta_c < 180° \tag{2}$$

For a 12-pulse converter, the crest fundamental line current into the converter is well-approximated by the expression [2]

$$I_m = \frac{4\sqrt{3}}{\pi} I_{dc} \tag{3}$$

where I_{dc} is the converter direct current. If converter losses are neglected, the fundamental power factor is given by

$$\cos\phi = \frac{\pi V_{dc}}{6\sqrt{3}E_m}, \quad 0° < \phi < 180° \tag{4}$$

where V_{dc} is the converter direct voltage and ϕ is the angle that the fundamental converter current lags the bus voltage. Equation (4) is valid for both rectifier and inverter operation. From Fig. 1 it is also evident that

$$i_q = i_m \cos(\delta_c + \phi) \tag{5}$$

$$i_d = i_m \sin(\delta_c + \phi) \tag{6}$$

The direct voltage output of the 12-pulse converter is represented in the simplified model by its average value [2]

$$V_{dc} = \frac{6\sqrt{3}}{\pi} E_m \cos\alpha - \frac{6X_\ell}{\pi} I_{dc} \tag{7}$$

where α is the ignition delay angle and X_ℓ is the per phase leakage reactance of each transformer. Equation (7) is valid if α changes slowly relative to the switching rate of the converter. Assuming an inverse cosine method is used to generate ignition pulses, Eq. (7) may be written

$$V_{dc} = \frac{6\sqrt{3}}{\pi} e_c - \frac{6X_\ell}{\pi} I_{dc} \tag{8}$$

where e_c is the converter control signal, which may in general be a function of several system variables, that is

$$e_c = f(V_{dc}, I_{dc}, E_m, E_{ref}, E_{ext}) \tag{9}$$

where E_{ref} may be a constant current reference or a constant power reference, and E_{ext} is an external modulation signal for some special control purpose.

For control studies, a superconducting magnet can be modeled as simply a linear inductance [3,4], so that

$$V_{dc} = L \frac{d}{dt} I_{dc} \tag{10}$$

An equivalent circuit [5] which is valid for several promising battery technologies is shown in Fig. 2.

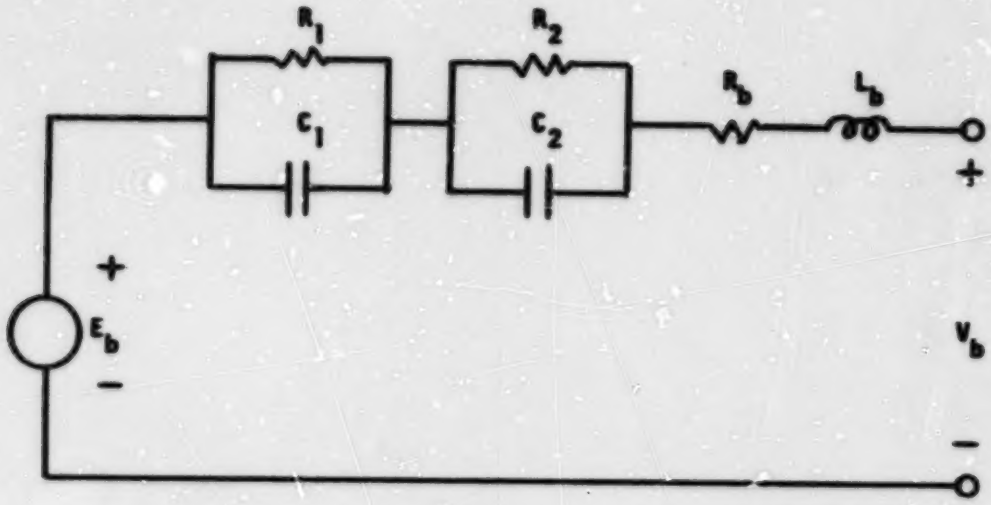

Fig. 2 Storage Battery Equivalent Circuit

Use of storage batteries with line commutated converters will require the use of a series inductance; therefore, the direct voltage and current are related by

$$V_{dc} = L \frac{d}{dt} i_{dc} \pm V_b \tag{11}$$

$$V_b = f(I_{dc}, E_b) \tag{12}$$

where the + sign in Eq. (11) is for charging and the - sign for discharging of the battery. The change in sign is due to the reversing switchgear required for batteries operating with LCC interfaces.

The resulting simplified model for a line-commutated IC or BC unit consists of a simultaneous solution of Eqs. (1) - (12). Figure 3 shows the solution flow used in the model. For the study of a specific system or application, it is clear that Eq. (9) would be more explicitly defined.

1.2 Computer Simulations

For purposes of verification of the simplified line-commutated IC and BC models, two hybrid computer simulations were developed for the one-machine/

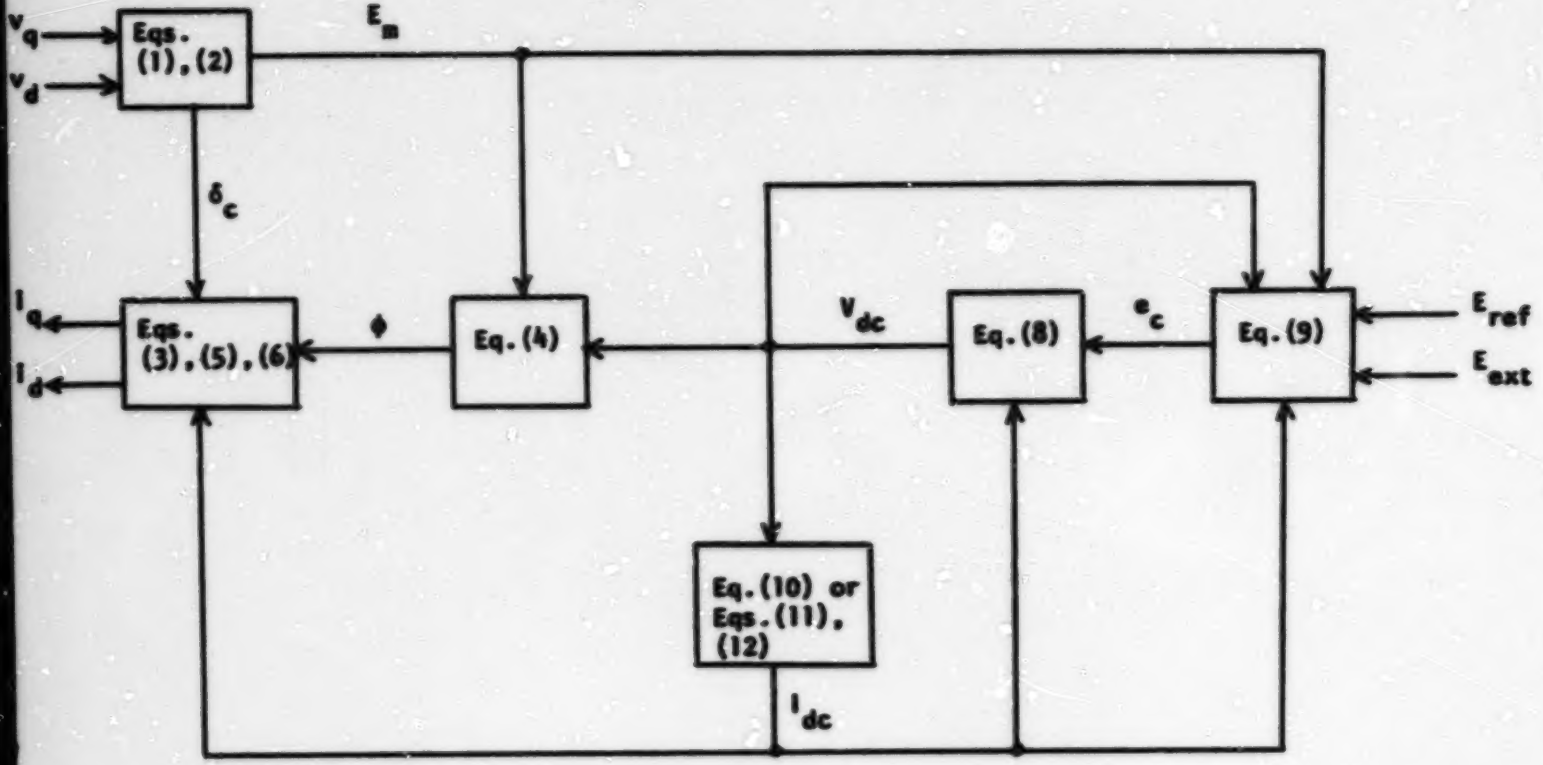

Fig. 3 Block Diagram of Simplified Model

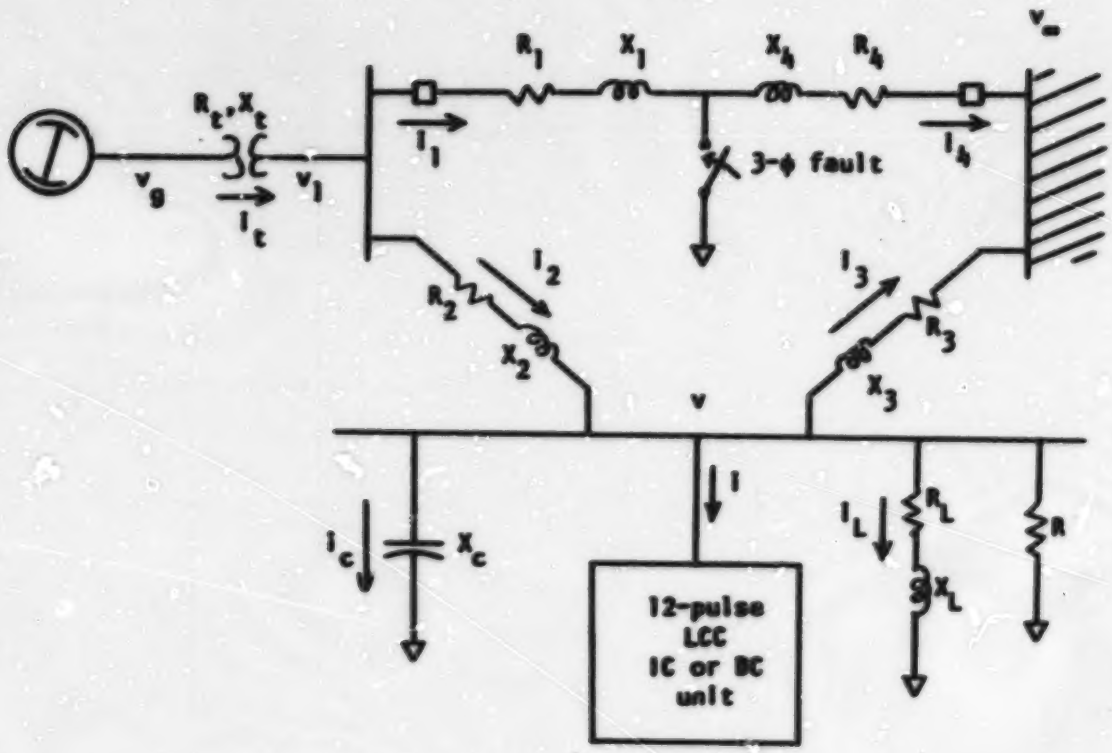

Fig. 4 Power System Simulated

infinite bus system shown in Fig. 4. In one simulation, reference frame theory is used to reduce the system to a simplified representation which is compatible with the simplified models of the storage units. The other computer simulation is a detailed three-phase representation of the system, which includes an individual valve representation of the converter. In both simulations, Park's equations are used to represent the synchronous machine. An IEEE Type 1 excitation system is used with the machine simulation.

In the simplified simulation of the system the transmission network, loads, and infinite bus are represented in the synchronously rotating reference frame, as are the simplified models of the IC and BC units. The machine is represented in a reference frame fixed in the rotor. If f^e is a variable in the synchro-

nous reference frame and f^r is the same variable in the rotor reference frame, the transformation which relates the two representations is

$$\begin{bmatrix} f_q^e \\ f_d^e \end{bmatrix} = \begin{bmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{bmatrix} \begin{bmatrix} f_q^r \\ f_d^r \end{bmatrix} \tag{13}$$

where δ is the rotor angle of the machine relative to the synchronous reference frame.

The control system used in the simulation of the IC unit is basically a power control, in which

$$e_c = \frac{\pi P_{ref}}{6\sqrt{3}\, i_{dc}} + \frac{X_\ell}{\sqrt{3}} I_{dc} \tag{14}$$

which is subject to the constraints

$$-E_m \cos\gamma_o + \frac{2X_\ell}{\sqrt{3}} I_{dc} \leq e_c \leq E_m \cos\alpha_o \tag{15}$$

where α_o and γ_o are the minimum ignition and extinction angles of the converter. The power reference is modulated with a feedback measurement of $\Delta\omega_r$, the change in machine speed from the synchronous speed, ω_e.

$$P_{ref} = K_m \Delta\omega_r \tag{16}$$

The control system used in the DC unit is basically a current regulator, in which

$$e_c = \frac{K}{S}(I_{ref} - I_{dc}) \tag{17}$$

which is also subject to the constraints given in Eq. (15). The current reference is again modulated with $\Delta\omega_r$.

$$I_{ref} = K_m \Delta\omega_r \tag{18}$$

This reference has limits imposed for maximum and minimum currents in the converter, that is

$$I_{min} < I_{ref} < I_{max} \tag{19}$$

1.3 Computer Studies

Several computer studies were made with the system described, for comparison of the simplified and the detailed representations. The studies included in this report were made for an equivalent 1000 MVA machine, and a 10 MW and 70 MW IC and BC unit. The nominal per unit parameters of the machine, transmission network, and the load, on the power base of the machine, are listed below.

Machine H = 2.95 sec

r_s = stator resistance	= 0.003 pu	$X_{\ell kq}$ = q-axis damper leakage reactance	= 0.05233 pu
$X_{\ell s}$ = stator leakage reactance	= 0.093 pu	r_{kd} = d-axis damper resistance	= 0.00789 pu
r_f = field resistance	= 0.00082 pu	$X_{\ell kd}$ = d-axis damper leakage reactance	= 0.025 pu
$X_{\ell f}$ = field leakage reactance	= 0.10746 pu	X_{mq} = q-axis magnetizing reactance	= 1.12 pu
r_{kq} = q-axis damper resistance	= 0.00759 pu	X_{md} = d-axis magnetizing reactance	= 1.44 pu

Machine Excitation (IEEE Type 1)

K_A = 50	K_F = 0.013	V_{ref} = 1.0 pu
T_A = 0.02 sec	T_F = 0.38 sec	S_{EMAX} = 0.19 pu
K_E = -0.02	V_{RMAX} = 1.0 pu	S_{EMIN} = 0.08 pu
T_E = 0.05 sec	V_{RMIN} = -1.0 pu	

Machine Transformer

R_t = 0.01 pu	X_t = 0.1 pu

Transmission Network

$v_\infty = 1.0$ pu $\quad R_2 = 0.01$ pu $\quad R_3 = 0.05$ pu

$R_1 = R_4 = 0.03$ pu $\quad X_2 = 0.1$ pu $\quad X_3 = 0.5$ pu

$X_1 = X_4 = 0.3$ pu

Loads

$R_L = 2$ pu $\quad X_L = 1$ pu $\quad R = 10$ pu

The nominal parameters associated with the IC and BC units, on the power base of the converter, are given below. The inductance of the superconducting magnet and the battery parameters were determined from information in previous investigations [5,6].

PFC Capacitor

$X_C = 0.75$ pu

Converter

$X_\ell = 0.2$ pu

Converter Control

$\alpha_o = 6°$ $\quad K_m = 0.2652$ pu

$\gamma_o = 15°$ $\quad I_{max} = 1$ pu

$K = 6.046$ pu $\quad I_{min} = 0.2$ pu

Superconducting Magnet

$L = 43.77$ pu

Battery

$R_b = 0.05618$ pu $\quad L = 0.00864$ pu

The per unit system for representing the parameters and variables associated with the IC and BC units, uses the rated value of E_m as a base voltage, and the base impedance is computed from

$$Z_b = \frac{3}{2} \frac{(E_m \text{ kv})^2}{\text{total converter MVA}}$$

This means that the leakage reactance of each converter transformer, on its own base, is actually 1/2 of that given above (i.e., $X_\ell = 0.1$ pu on each transformer base). Also, the rated direct voltage and current of the 12-pulse converter become approximately 3 pu and 0.5 pu, respectively, in this per unit system.

Figures 5-11 are sample results from the simulation studies performed. In each case waveforms from the simplified representation are compared with corresponding results taken from the detailed representation. The variables recorded are listed below.

T_e = Machine Electrical Torque

$\frac{\Delta\omega_r}{\omega_e}$ = Ratio of Machine Speed Change to Synchronous Speed

δ = Machine Rotor Angle

E_x = Machine Excitation

v_{ga} = Phase 'a' Machine Terminal Voltage

E_{gm} = Crest Machine Terminal Voltage

v_a = Phase 'a' Converter Bus Voltage

E_m = Crest Converter Bus Voltage

V_{dc} = Converter Direct Voltage

I_{dc} = Converter Direct Current

The waveforms shown in Figs. 5-11 are system responses to a three-phase fault at the middle of the transmission line between the machine bus and the infinite bus. The fault is cleared after 0.25 sec. The electrical transients shown on

the recordings clearly mark the occurrence of the fault and its subsequent clearing. For simplicity, the prime mover torque was held constant during the entire transient shown in each recording. Figure 5 shows the fault response of the nominal system with neither storage unit connected to the system. The corresponding waveforms must show nearly exact agreement, since the simplified models of the IC and BC units are not considered. Figure 5 serves as a reference for Figs. 6-11, where the IC and BC units are controlled to damp the machine swings, and the accuracy of the simplified models becomes important.

Figures 6-8 show the fault responses of the system when the 10 MW and 70 MW IC units are operated. In each case the prefault state of the IC unit was assumed to be zero direct voltage and rated direct current. Figure 6 was taken for the 10 MW unit. Comparing Fig. 6(a) with 6(b), it is clear that the corresponding waveforms show nearly exact agreement. Due to the small size of the IC unit relative to the machine capacity, the damping provided by the unit is noticeable but not dramatic when compared to Fig. 5. Figure 7 was taken for the 70 MW unit operated with the nominal system. For this stronger unit, the responses using the simplified model are again nearly identical to those obtained using the detailed representation. Figure 7 also shows that the 70 MW IC unit provides considerable damping to the system; some benefit is even obtained on the first few swings. Figure 8 was also taken for the 70 MW unit, but the line parameters were changed to locate the IC unit more remote from the machine. The results shown in Fig. 8 further verify the simplified model, and also indicate the decreased effectiveness of the control for a more remotely located IC unit.

Figures 9-11 show the fault responses of the system when the 10 MW and 70 MW BC units are controlled in a similar manner to the IC units. However, as

discussed earlier, the BC control is basically a current regulator instead of a power control. Also, because reversal switchgear is required to change the battery operating mode between charge and discharge, the effectiveness of a full-range control is questionable. For this reason, the results shown here were restricted to one mode of battery operation, namely the charge mode, without reverse switching during the fault transient. In each case the prefault state of the battery was assumed to be at rated direct current and a partially charged condition corresponding to E_b = 2.6 pu. Figure 9 was taken for the 10 MW BC, while Figs. 10 and 11 were taken for the 70 MW unit. Again, a comparison of results using the simplified model with those obtained from the detailed representation show nearly exact agreement. The effects of the BC unit on the system also follow the same trends as the IC unit, but the effectiveness of the BC control is not as pronounced since the battery cannot operate over its full range. The BC unit has no effect on the first swing, since before the fault is cleared battery charging ceases due to the voltage dip at the converter bus. The IC unit does not suffer from this condition, since it can absorb or deliver significant energy over a wide range of bus voltages.

1.4 Conclusions

From the comparison of results between the simplified and the detailed simulations of the system, it appears that the simplified models of superconducting magnets and storage batteries with line commutated converter interfaces are excellent representations for control investigations. The studies also indicate that both types of storage units could be utilized to enhance power system stability, but that the superconducting magnet has some inherent control advantages over the storage battery when used for this purpose with line commutated converters.

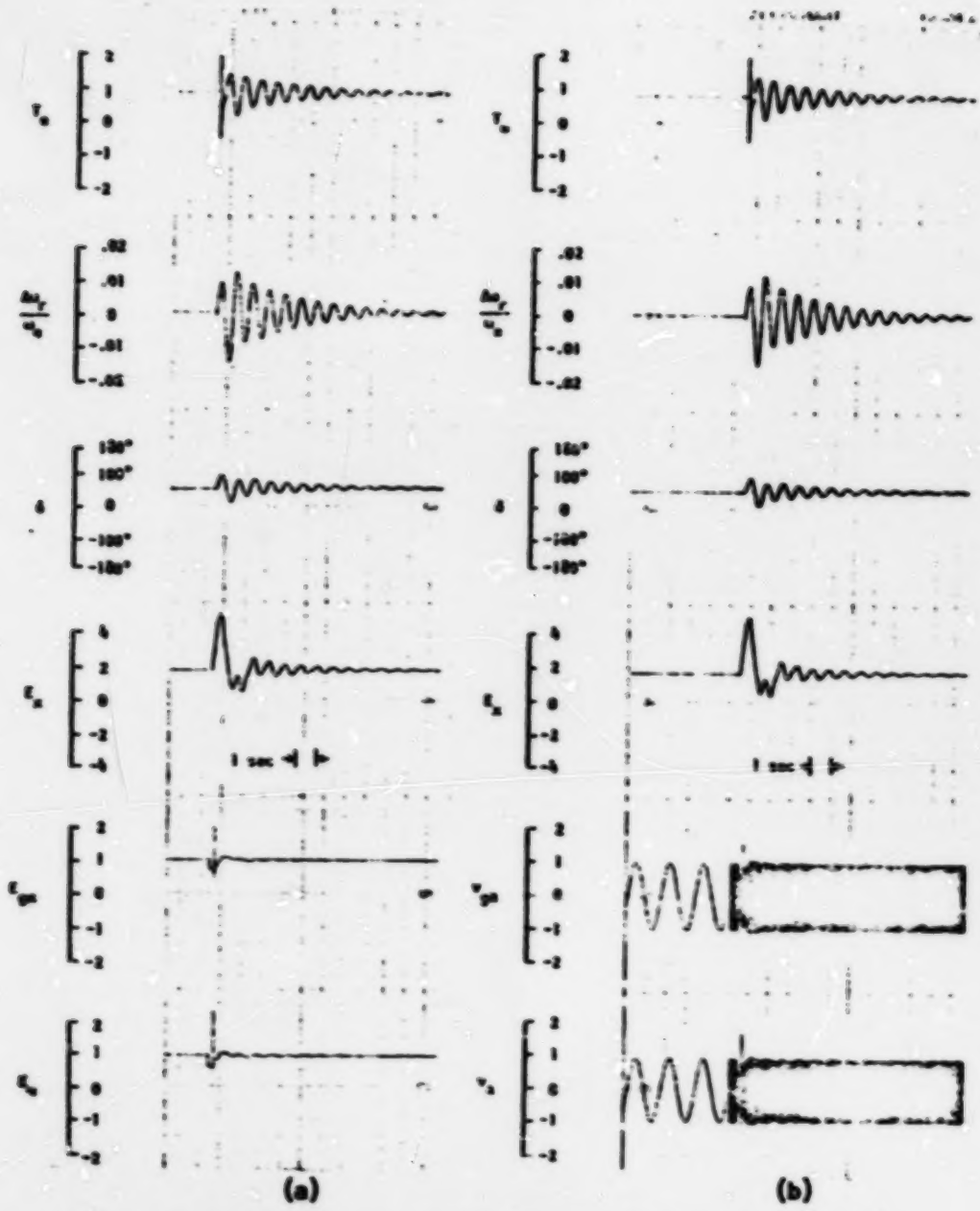

Fig. 5 Fault Response of Nominal System Without Storage Unit Control: (a) Simplified Model, (b) Detailed Simulation

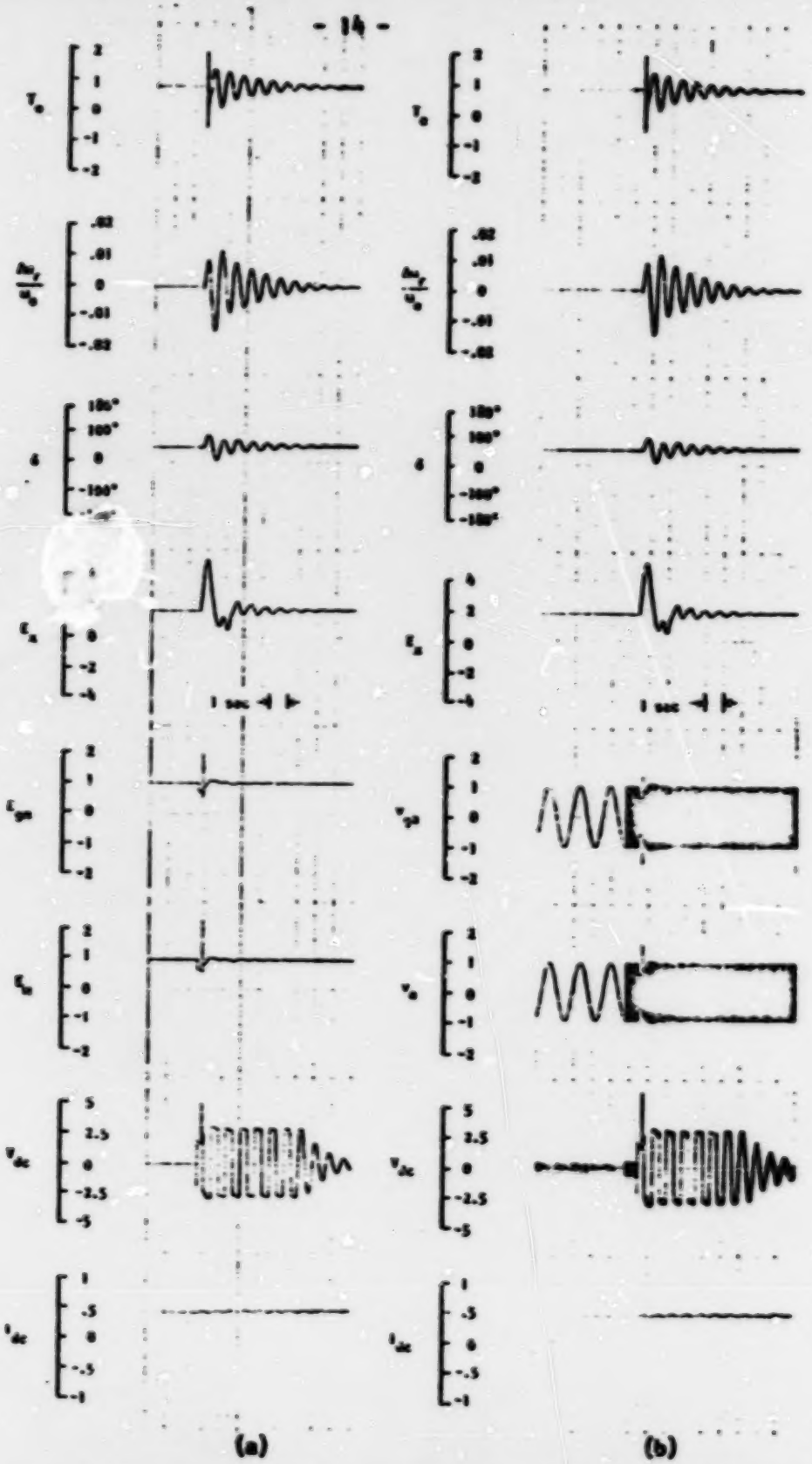

Fig. 6 Fault Response of Nominal System with Controlled 10 MW IC Unit: (a) Simplified Model, (b) Detailed Simulation

Fig. 7 Fault Response of Nominal System with Controlled 70 MW IC Unit: (a) Simplified Model, (b) Detailed Simulation

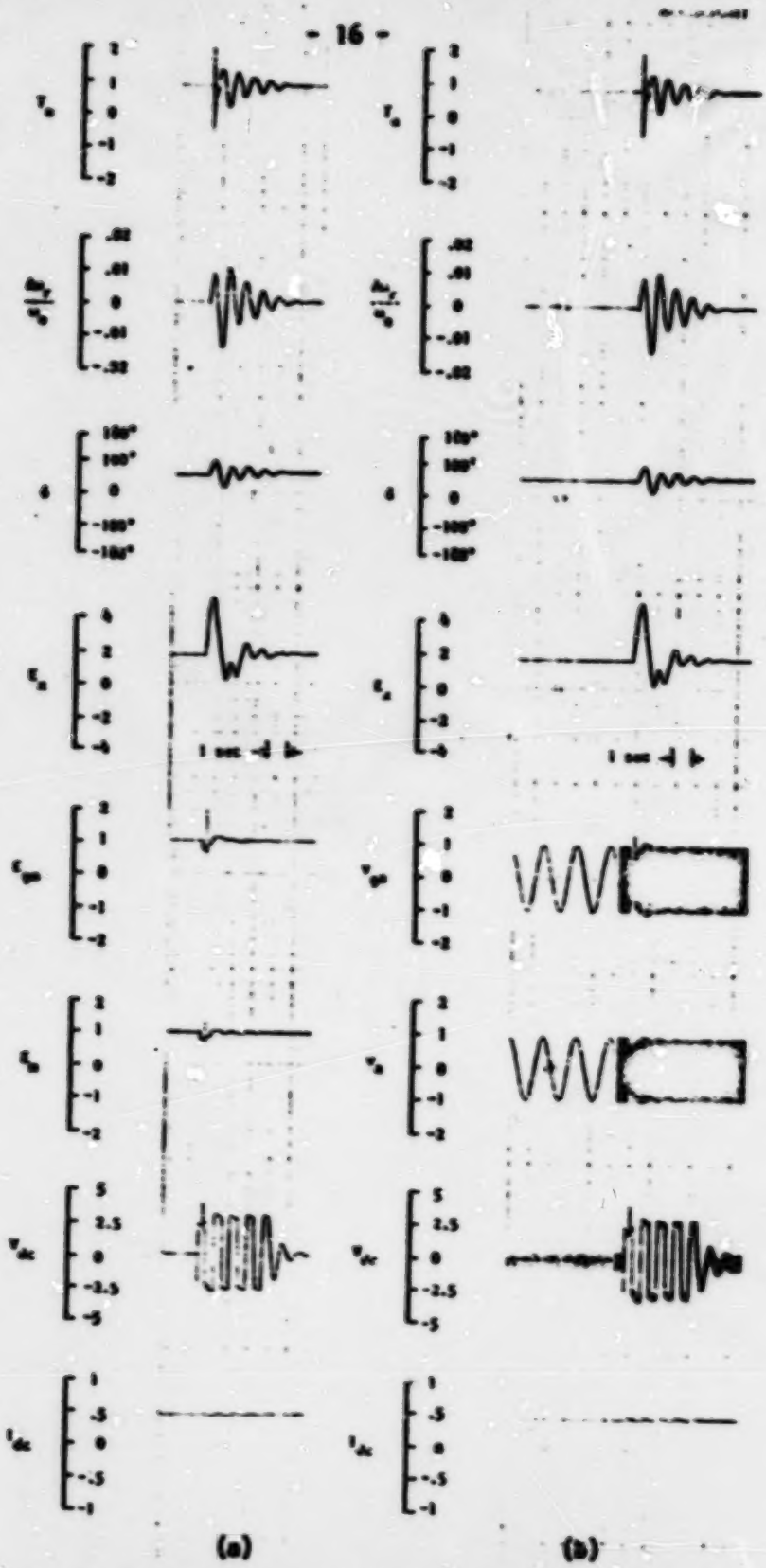

Fig. 8 Fault Response of System with $R_2 = R_3 = 0.03$ pu, $X_2 = X_3 = 0.3$ pu, and Controlled 70 MW IC Unit: (a) Simplified Model, (b) Detailed Simulation

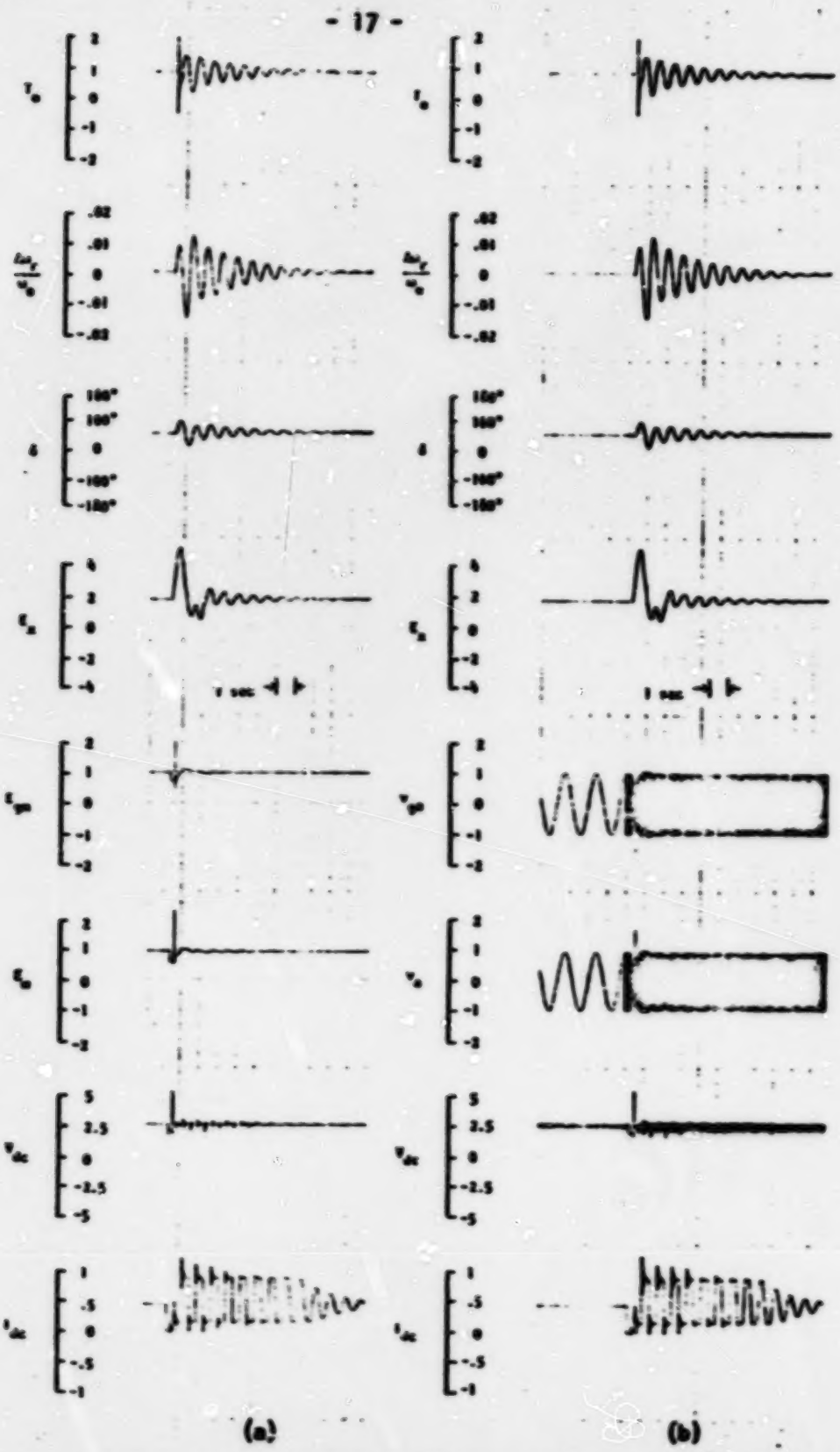

Fig. 9 Fault Response of Nominal System with Controlled 10 MW DC Unit: (a) Simplified Model, (b) Detailed Simulation

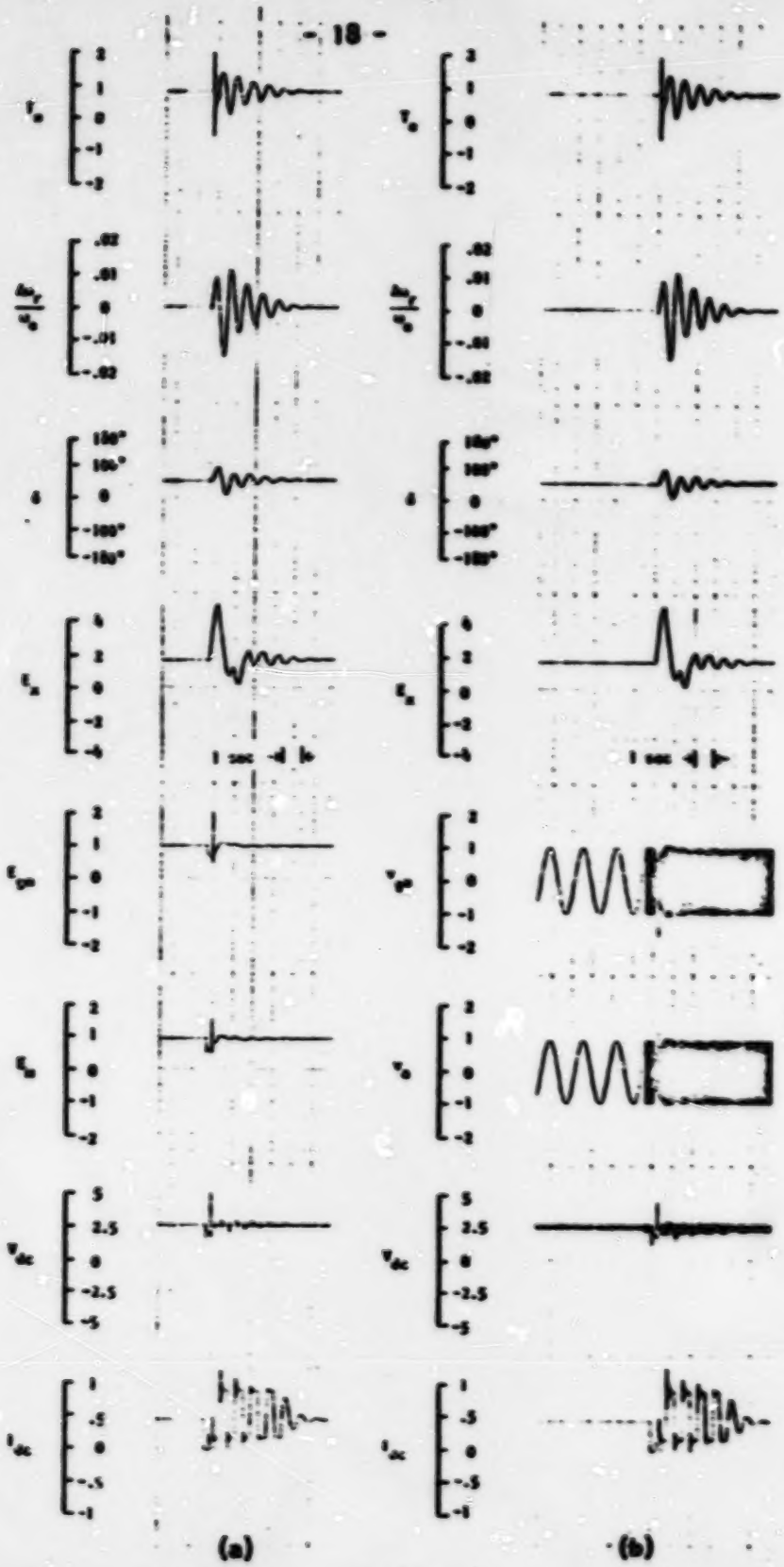

Fig. 10 Fault Response of Nominal System with Controlled 70 MW DC Unit: (a) Simplified Model, (b) Detailed Simulation

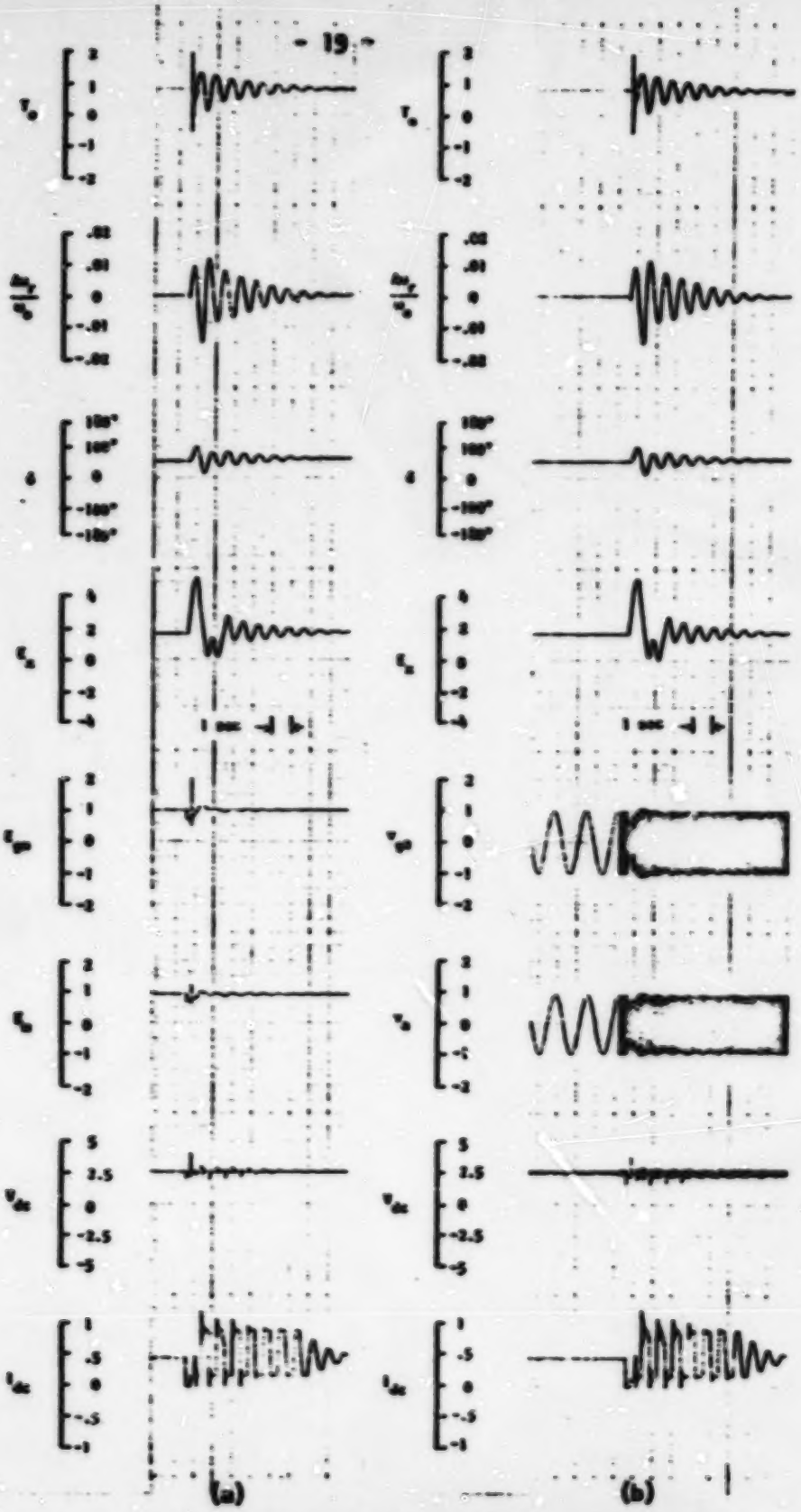

Fig. 11 Fault Response of System with $R_2 = R_3 = 0.03$ pu, $X_2 = X_3 = 0.3$ pu, and Controlled 70 MW DC Unit: (a) Simplified Model, (b) Detailed Simulation

1.5 References

1. H. A. Peterson and P. C. Krause, "A Direct - and Quadrature - Axis Representation of a Parallel AC and DC Power System," IEEE Trans. PAS, March 1966, pp. 210-225.

2. E. W. Kimbark, Direct Current Transmission, Vol. 1, Wiley-Interscience, 1971.

3. "Wisconsin Superconductive Energy Storage Project," Vol. 1, University of Wisconsin, July 1974.

4. "Wisconsin Superconductive Energy Storage Project," Vol. 2, University of Wisconsin, January 1976.

5. "The Interaction of Electrical Distribution Systems with Batteries and Fuel Cells," EPRI 418 Final Report, Purdue University, May 1976.

6. W. V. Hassenzahl and H. J. Boenig, "Superconducting Magnetic Energy Storage," World Electrotechnical Congress, Moscow, USSR, June 1977.

SECTION 2

REDUCED ORDER MODELS OF THE DOUBLY-FED INDUCTION MACHINE

At the present time, work is underway in developing reduced order models of induction machines. The reductions are those in which the $p\psi$ terms are neglected in (1) the stator voltage equations, (2) the rotor voltage equations and (3) both the stator and rotor voltage equations. Studies are being conducted using an eigenvalue approach and an analog computer simulation to determine the validity and limitations of each of these reductions. Modes of operation, machine parameters and application of reference frame theory are all being considered in this investigation. Although the interest in this contract is doubly-fed induction machines, the work being done is applicable to induction machines in general. In particular, this work should be of value in simply representing induction machine loads in dynamic and transient stability studies of large power systems.

SECTION 3

POWER SYSTEM IDENTIFICATION

In the first months of contract performance, work has been done which contributes to the first two tasks in the scope of work, while directly accomplishing neither of these tasks.

3.1 Load Variation Model

A power system in steady state is continually perturbed by small variations in the system loads. As a result, signals measured on the system display continuous motion. The character of these signals is not that of white noise, but shows distinct correlations, presumably due to system electromechanical motion.[1]

Contacts have been made with two individuals who have experience in making power system measurements in order to examine the spectral content of the signals. Dr. G. L. Park of Michigan State University expressed his belief that the forcing function for power system disturbances is a variation in load real and reactive power in the form of a Weiner process (i.e., white noise passed through an integrator). He also added that for practicality in simulation, it is probably necessary to limit the nagnitude of signal energy density at low frequency. Thus a reasonable load variation model is white noise passed through a first order lag filter, where the time constant of the filter is large. Mr. R. L. Cresap of BPA pointed out that since a time series of measurements is finite, it is probably impossible to distinguish a Weiner process signal from white noise that has passed through a first order lag filter of sufficiently large time constant. He also added that separate time series taken at the same location to indicate that the process is non-stationary.

It is this investigator's opinion that Weiner process variation of load is intuitively reasonable. In developing a simulation for the identification experiments, load variations should be represented as white noise passed through a first order lag filter. The time constant of the filter should be large enough to be inconspicuous to a time series of measurements of the anticipated length.

In formulating state variable models of power systems, it is not convenient to have a bus (load bus) where P and Q (real and reactive power) are directly represented as independent random processes. Rather, the following approach has been taken. Loads are modeled as a series combination of an inductor, a resistor, and a voltage source. The inductor and resistor values are determined by the mean P and Q of the load, and the voltage source is an independent zero mean process. Circuit equations can easily be written for this model and it can easily be shown that if network dynamics are neglected, the spectral characteristics of the voltage sources become, for small signal considerations, those of P and Q for the load. Furthermore, the voltage source spectral characteristics carry over in any orthagonal transformation of system coordinates. For example, if the voltage sources are three independent Weiner process in a,b,c phase coordinates, they are also independent Weiner processes in dq0 coordinates that rotate at any velocity.

A possible alternative load model has been considered but not yet fully investigated. It is an induction motor with a load torque that is a random process. By appropriate adjustment of the inertia constant, a filtering effect can be achieved. A model such as this would be quite appealing intuitively.

3.2 Direct Computation of Measurement Spectra

As a preliminary task to taking time series measurements on a simulated

system, the capacity has been developed to calculate measurement power spectra directly. This is essentially a matter of writing the transfer function between the random process input and the desired measurement. Canonical forms for the system equations are particularly convenient for this task.[2,3] A sample result is Fig. 1, which is the spectral density function of real power fluctuations at the infinite bus in a one machine, load, line, and infinite bus system. The system model is tenth order because machine damper windings and network state variables are included. The load model is as described previously. As was evident in the system measurements reported in Ref. 1, the dominant feature of this power spectrum is due to rotor motion (this system has a complex conjugate eigenvalue pair of $0.68 \pm j9.90$ sec^{-1}).

The capacity to make direct calculations of signal spectral densities is felt to be quite valuable to the project for the following reasons.

1. It can be used to establish the sampling "window" that is required for time series measurements.
2. It is a check on time series measurements taken from a simulation.
3. It can be used to establish sensitive points in the system, at which much information is contained in measurements.
4. It gives a good indication of how system models should be simplified. For example, a tenth order system model was probably not necessary to determine Fig. 1. The standard practice of neglecting network and stator transients should be quite acceptable.

3.3 Work Planned

With approval of the ERDA technical staff, the research will proceed as follows in the near future:

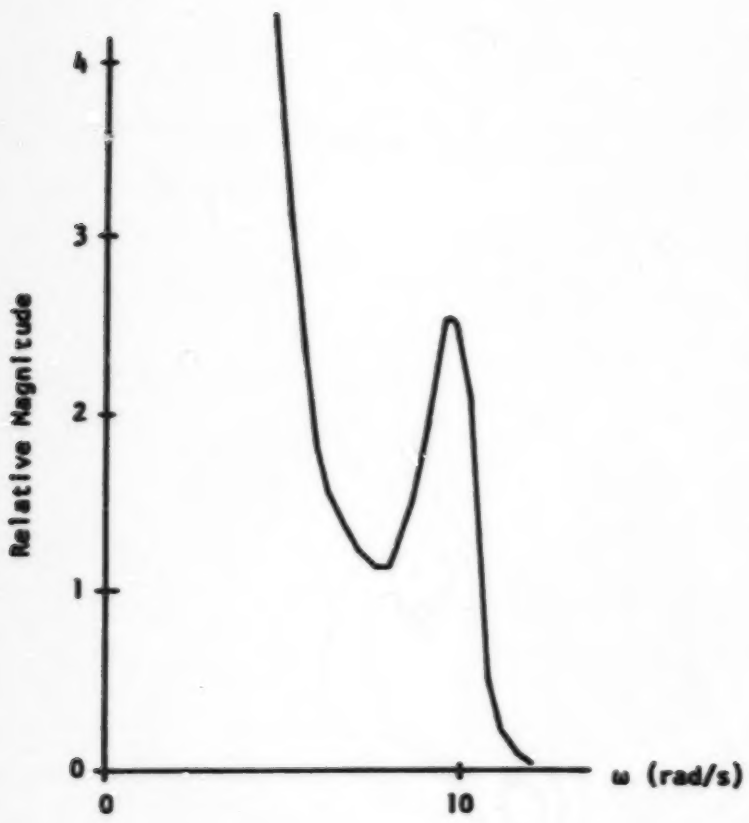

Fig. 1 Spectral Density of a Real Power Measurement

1. With a one machine-infinite bus system, determine the machine-network model order reduction that it is possible to achieve and still maintain recognizable signal spectral densities. A reduced order model is to be incorporated into identification algorithms and is not used in simulations. It is expected that the reduced order model corresponding to Fig. 1 will have as few as two or three states since exact damper winding configuration is probably not distinguishable in a time series sampling. The reductions achieved will be assumed to apply to multiple machine systems.
2. With the same simple one machine system, determine the effect of prime mover and excitation systems on the measurable spectral densities. From this, a decision will be made about inclusion of these subsystems in an identification algorithm model.

Note that in items 1 and 2 above, simple visual inspection of spectral density plots is probably not an adequate means for judging appropriate model composition. Rather, the relative success of standard least squares parameter estimators is more reliable.

3. Construct an analog one machine system simulation with an appropriate load variation. Gaussian noise generators are available in the Energy System Simulation Laboratory for this purpose. From this simulation, the constraints on time series sample sequences, adequate to reconstruct the proper spectral density functions, will be determined.

Completion of the above three items will bring this project to the point where consideration of identification algorithms can begin.

3.4 References

1. K. H. Andrews and G. L. Park, "Dynamic Frequency, Power and Voltage Measurement," ISA International Conference, Philadelphia, 1970, Paper No. 506.

2. W. G. Tuel, "On the Transformation to (Phase-Variable) Canonical Form," IEEE Trans., Vol. AC-11, p. 607, July 1966.

3. D. G. Luenberger, "Canonical Forms for Linear Multivariable Systems," IEEE Trans., Vol. AC-12, p. 290, June 1967.